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A Photographic Method for Determining Mineral Reflectances in Underground Mines

By Alan G. Mayton



UNITED STATES DEPARTMENT OF THE INTERIOR



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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°	degree	'	minute of arc
ft	foot	mm	millimeter
ft ²	square foot	pct	percent
in	inch		

A PHOTOGRAPHIC METHOD FOR DETERMINING MINERAL REFLECTANCES IN UNDERGROUND MINES

By Alan G. Mayton¹

ABSTRACT

The Bureau of Mines conducted a study to (1) determine from laboratory tests the feasibility of a photographic method for determining reflectances that may be applied to measuring in-mine mineral reflectances and (2) formulate a procedure for collecting and analyzing the data. The method uses a 35-mm camera with automatic flash and a gray-scale reflectance standard to collect on film the reflectivity data in underground mineral mines. After the film is processed, the data on the photographic prints are analyzed in the laboratory with a photometer. Test results show the photographic method can provide values of reflectance to within ± 5 pct of full scale (full scale = 100 pct). The method's usefulness for determining reflectivity values, within similar limits of absolute percent error at the lower end of the scale, however, has not been completely resolved by the study and consequently warrants further investigation. The method offers an acceptable means for collecting and analyzing reflectivity data for reflectivities at the higher end of the scale, i.e., 50 pct or above; it should be used with caution when reflectivity values are below 50 pct. Four films were evaluated; all gave relatively satisfactory results.

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INTRODUCTION

The passage of the Federal Coal Mine Health and Safety Act of 1969 gave the U.S. Department of Interior authority to recommend minimum illumination standards for mining environments. This authority was subsequently transferred to the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, with the passage of the Federal Mine Safety and Health Amendments Act of 1977. Since then, the mutual efforts of the Bureau of Mines and MSHA have given major attention to underground mining, to the extent that 85 pct of all required underground coal mining machinery is equipped with an approved lighting system (1).² In view of the progress in underground coal mines, the Bureau has increased its activity toward the development of illumination requirements for underground metal and nonmetal mines.

In recommending illumination standards, there are three essential elements to consider: (1) illuminance, the light emitted from a light source; (2) luminance, the light the eye sees; and (3) reflectance, the ratio of luminance to illuminance. Of these three elements, luminance would be the ideal method of expressing lighting standards because it relates directly to what the eye actually sees. If the reflectance of surfaces is known, the luminance can be calculated provided the illuminance (readily available from manufacturers) and the distance from the source to the surface are also known. Thus, accurate measurements of reflectance can provide the vital link in

the development of appropriate lighting standards or guidelines (2).

Research has demonstrated that photography can be a useful means of measuring brightness or luminance for, e.g., city streets (3-7). In addition to providing results comparable in accuracy to direct measurements, the method offers the advantages of more comprehensive data and reduced time in collecting the data (3).

Since a large amount of reflectivity data is necessary to adequately describe the working environments in metal and nonmetal mines, the Bureau conducted a research project to develop a quick and simple method for collecting these data at low cost with relatively unskilled personnel. The objective of the program was to use black-and-white photography to capture in-mine, mineral reflectivity data on film so that these data could be processed into photographs and analyzed photometrically in the laboratory. In general, the method involves photographing selected in-mine, mineral surfaces with a relatively easy-to-use camera and automatic flash. A reflectance standard, called a gray scale, is included in each photographic scene by attaching it to the surface of interest. The photographs resulting from the exposed film will then provide data of known and unknown reflectances and permit measurements of luminance with a photometer for the desired surfaces in each scene. These data in turn are used to calculate the reflectance of the unknown mineral surface (1).

FILM

Black-and-white film, as opposed to color film, was chosen for several reasons:

1. The reflectance of spectrally non-selective gray objects remains constant for all light sources (8).

2. The reflectance of color surfaces varies with the type of lighting; e.g., fluorescent versus incandescent lighting.

3. Color is unimportant relative to the mineral surfaces to be photographed.

4. The gray scale used as a reflectance standard is black and white.

²Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

As recommended by Lewin and Bell (5), Kodak Panatomic-X film was used in the initial laboratory experiments. The

other films tested were Agfapan 100, Ilford XPl, and Kodak Technical Pan. Time constraints did not permit the

evaluation of other suitable films. Details of the film testing are given in the appendix.

PHOTOGRAPHIC METHOD

Merritt, in his report on Bureau of Mines contract J0318022, recommended a photographic method for measuring in-mine reflectance (9). The following procedures incorporate some of Merritt's methodology; however, the procedures are largely based on the results and experience of this study. Some helpful information is also included from Trotter's paper on reflectance measurements in underground mines (2). Note the following procedure applies only to underground mines classified as nongassy, primarily noncoal mines.

COLLECTION OF REFLECTIVITY DATA

1. Select a good-quality 35-mm SLR camera with a standard 50-mm lens.

2. Select a flash unit³ that is compatible with the angle of view; in other words, a flash that will provide a uniform distribution of light over the approximate 10.7-ft² area of the scene to be photographed (a camera-to-subject distance of approximately 6 ft).

3. Before entering the mine, load the camera with film. Set the camera to operate at the proper ASA and "snap off" several frames to assure that the initial photographs to collect the data will not have been tainted from loading the film.

4. After entering the mine, select a location to be photographed, preferably one that is relatively "flat" and "smooth." Extinguish all luminaires in the area except your own caplamp.

5. On a 5- by 7-in index card, identify the mine location of the scene to be photographed by using a marker pen to

print letters and/or numbers at least 1-1/2 in high. Attach this card and the gray scale adjacent to the area of interest by using caulking compound and gun or other suitable method.

6. Position the camera (on a tripod, if possible) approximately 6 ft from the area or scene to be photographed.

7. Make necessary camera and flash adjustments. Remove caplamp⁴ from hardhat and place around your neck so that it does not illuminate the area to be photographed.

8. Take a flash photograph so that the gray scale (fig. 1) and the identification card are included in the scene.

Gray scales should be made in the laboratory either from commercially available gray-scale standards or suitable art-style papers tested previously with a Pritchard or similar photometer to provide the desired reflectances. Considering the dust, dirt, and humidity of the mining environment, the latter may be more economical. Typically, segments of the gray scale should be 1-1/2 in square and chosen to represent a value of reflectance that falls within each decade on a scale of reflectance from 0 to 100. The gray scale should have a stiff rigid backing and should fold for ease of storage and carrying. In general, gray scales should be discarded when they become soiled or wet. Groups of identification cards can be placed in a sealed plastic bag, whereas the gray scales should be individually wrapped and sealed in plastic bags.

The importance of proper film processing cannot be overemphasized. At the least, the user of this method should ensure that the film laboratory to which the film is sent is capable of doing

³The method includes use of a flash to facilitate collecting the reflectivity data quickly and efficiently with sufficient accuracy. Flash usage seems acceptable when one considers, in actual practice, the wide variation that is found in reflectance values across a coal face.

⁴Caplamp illumination is excluded because it is not uniform; a uniform distribution of light is critical in photographing mineral surfaces.

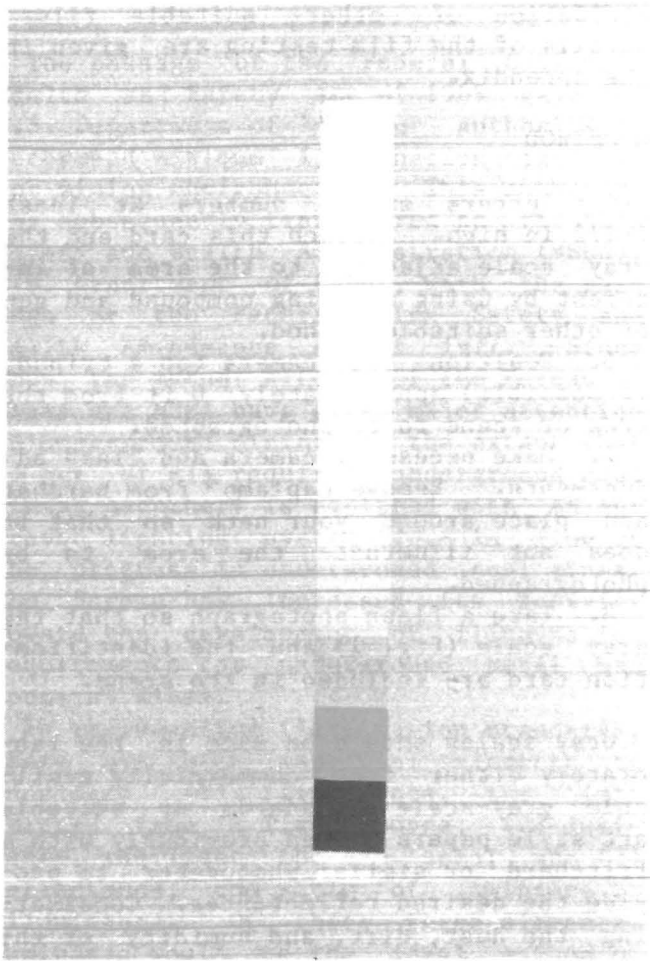


FIGURE 1.—Photograph of gray scale.

and will do the processing according to development specifications. Preferably, the prints should be 5- by 7-in size with a matte finish.

ANALYSIS OF REFLECTIVITY DATA

1. If possible, obtain a positioning device capable of holding and moving a photograph incrementally in the horizontal and vertical planes. This will facilitate the photometric analysis.

2. Locate the photometer at a distance from the photograph that would allow the use of the largest available measuring field aperture to measure the luminances of the gray-scale segment and mineral surface in the photograph. If available,

appropriate lens attachments can be used to aid in selecting the proper distance.

3. Calibrate the photometer to measure luminance.

4. Attach the photograph to be analyzed to the positioner, if applicable, with a paper glue stick. Press the photograph completely flat against the mounting surface of the positioner with a tissue or lint-free paper.

5. Measure the luminance of the unknown mineral surface.

6. Measure the luminance of the segment on the gray scale that appears closest in shade to the surface of interest.

7. Select and measure the luminance of another segment on the gray scale so as to "bracket" the luminance value measured for the mineral surface.

8. Calculate the reflectance of the mineral surface by using, as the reflectance standard, the gray-scale segment whose luminance is closest to the luminance of the mineral surface. Use the following equation:

$$R = \frac{L \cdot R_s}{L_s}$$

where R = reflectance of the mineral surface (unknown),

L = luminance of the mineral surface (measured),

R_s = reflectance of the gray-scale segment (known),

and L_s = luminance of the gray-scale segment (measured).

Variables that would cause the accuracy of reflectances to fall are a nonuniform distribution of light from the flash unit, specularity of the mineral surfaces photographed, inconsistencies in flash output, and an improper automatic exposure index within the camera. Details of the experimental study to develop the method are included in the appendix.

CONCLUSIONS

Test results show the photographic procedure can provide values of reflectance to within ± 5 pct of full scale (full scale = 100 pct). Although this is true, in general, the usefulness of the photographic method for determining reflectivity values (within similar limits of absolute percent error) at the lower end of the scale has not been

completely resolved by the study and consequently warrants further investigation. Thus, on the basis of this study, the method offers an acceptable means for collecting and analyzing reflectivity data for reflectivities at the higher end of the scale, i.e., 50 pct or above, and should be used with caution when reflectivity values are below 50 pct.

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APPENDIX.--EXPERIMENTAL METHOD

WORK DESCRIPTION AND PROCEDURES

During the initial part of the study, effort centered on three essential items:

1. Becoming familiar with the instrument of central importance to the study, the Spectra Pritchard photometer, model 1980A.
2. Purchase of a positioning device to hold the photographs and move them in the

horizontal and vertical planes to expedite the photometric analysis.

3. Obtaining a suitable gray scale for inclusion in each scene to be photographed to serve as a reflectance standard.

The Pritchard photometer (fig. A-1) was used to measure luminances from photographs comprising the desired reflectivity data of selected surfaces. A full

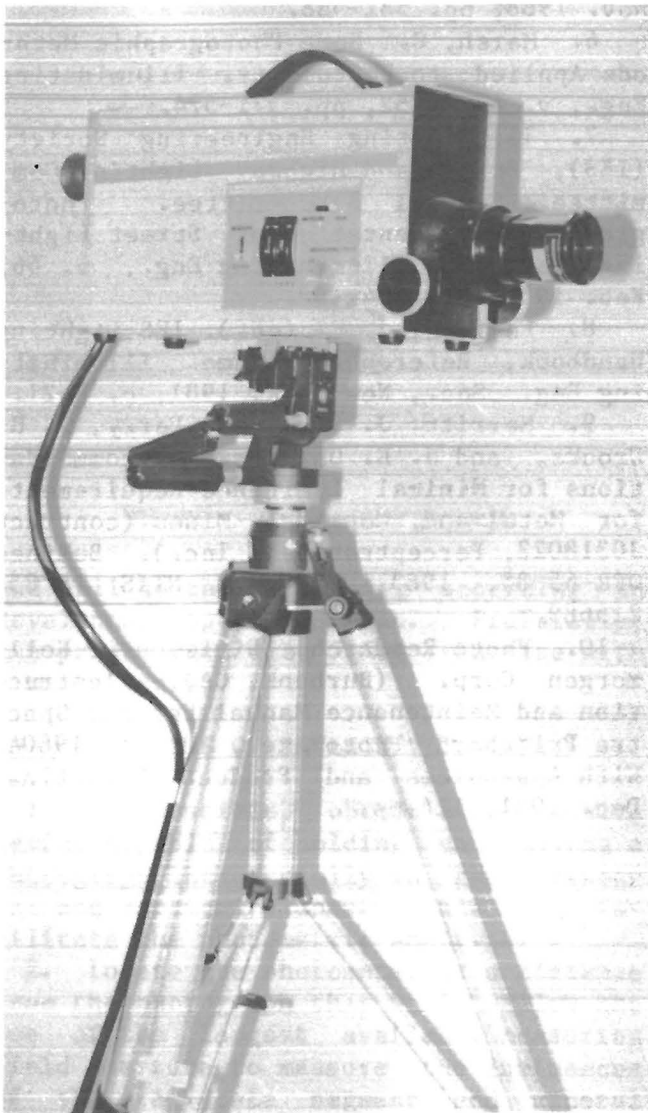


FIGURE A-1.—The Spectra Pritchard photometer used to measure luminance.

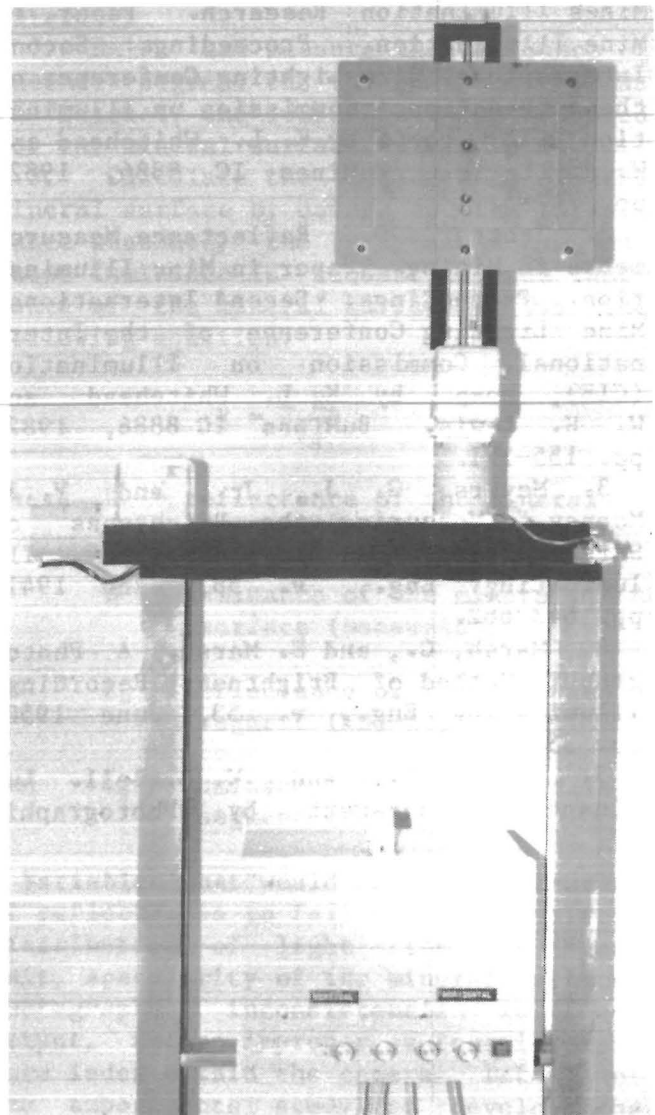


FIGURE A-2.—An x-y motion positioner for holding and moving photographs during photometric analysis.

explanation of the operation and use of the instrument is contained in its Instruction and Maintenance Manual (10).¹ An x-y motion positioner (fig. A-2) was purchased as a made-to-order item for the required application. The positioner was used to facilitate the photometric analysis of photographs. Later, a joystick was also purchased to use with the positioner to further expedite the photometric analysis. Paper gray scales with 12 steps or segments were obtained commercially and tried first; they proved unsatisfactory because they were limited to one scale-segment size and to a specific set of reflectance values. Next, flashed densities on paper with different values of reflectance were purchased commercially in order to make the gray scales according to the desired segment size and set of reflectance values. Subsequently, a laboratory test was performed on the flashed densities to check the specified reflectances. The test showed that only a small percentage met the manufacturer's specifications. The flashed densities were rejected for this reason and because their characteristic glossy finish was unfavorable. Consequently, individual neutral color standards in 8-1/2- by 11-in sheets were purchased from a different company. The specified reflectance of each sheet was checked using RS-1 and the photometer. Results of the reflectance check showed that these neutral standard sheets were quite satisfactory, varying within ± 4 pct of their nominal reflectance. Two six-step gray scales, featuring 1-1/2- by 1-3/4-in scale segments and reflectance values of 4.6, 10.4, 17.6, 30.0, 43.1, and 78.7 pct, were made first from 5- by 7-in "swatches" bought prior to the purchase of the 8-1/2- by 11-in sheets. Later, a 10-step gray scale was made from the 8-1/2- by 11-in sheets. This gray scale featured 1-1/2-in square segments with the following values of reflectance:

5.5, 15.6, 24.6, 37.5, 46.8, 54.8, 63.6, 73.4, 84.2, and 90.0. Figures A-3 and A-4 show the 6-step and 10-step gray scales, respectively.

The main part of the study consisted of a series of experiments conducted in the laboratory using 32- by 40-in cardboard sheets as the primary surfaces of interest in each scene. These approximately 1/16-in-thick sheets, henceforth referred to as "boards", featured a variety of neutral shades and colors. A standard Olympus 35-mm camera with automatic flash and standard 50-mm, 35- to 70-mm zoom, and 75- to 100-mm zoom lenses was used in all of the experiments (fig. A-5). The camera was mounted on a tripod, and the board and gray scale were taped to the laboratory wall. Camera-to-subject distances for experiments ranged from 6 to 10 ft. The small 6-step gray scale was used in the first two experiments, and the larger 10-step gray scale was used in the remaining experiments. The Pritchard photometer and the reflectance standard, RS-1 (fig. A-6), were used to determine the nominal reflectance of each board directly, while the Pritchard with the gray scale in each photograph was used to determine the reflectance of the board from each photograph.

A neutral test card was included in the scene with the board and gray scale in two of the experiments (fig. A-7). This was done to help in more effectively processing the film prints.

To determine the reflectance of the board, both directly and from the individual photographs, the following procedure was used. (Existing laboratory light was used in both cases). The photometer was positioned generally about 6 to 10 ft from the subject, and the appropriate aperture field (2', 6', 20', 1°, or 3°) was selected. While calibrating the photometer, the RS-1 plaque was taped to the surface of the board, taking care to avoid marring the surface. The luminance of the plaque was measured first. Then the plaque was removed, and the luminance of the board was measured.

¹Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

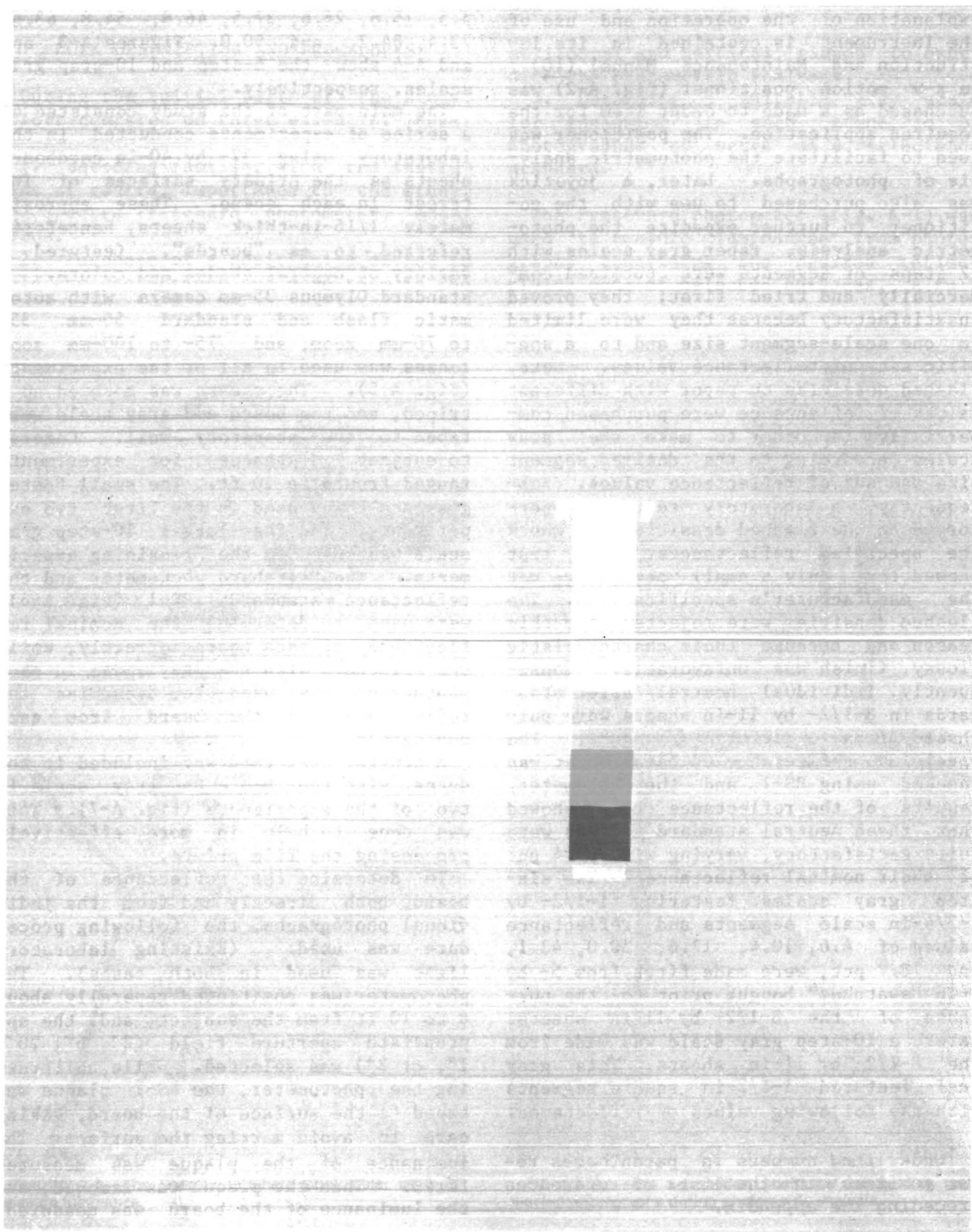


FIGURE A-3.—Board and six-step gray scale.

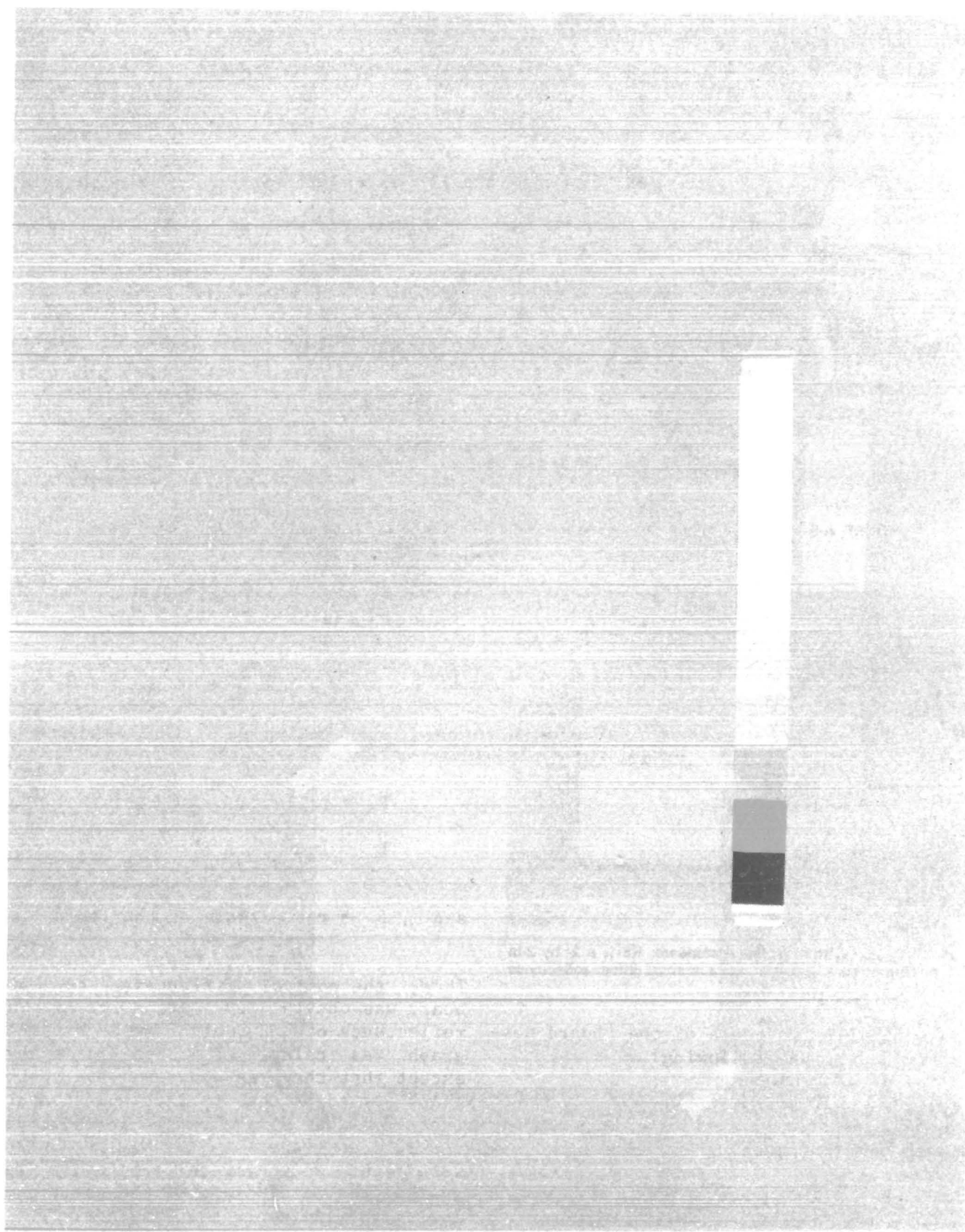


FIGURE A-4.—Board and 10-step gray scale.



FIGURE A-5.—Olympus 35-mm camera and automatic flash with 35- to 70-mm and 75- to 150-mm zoom lenses.

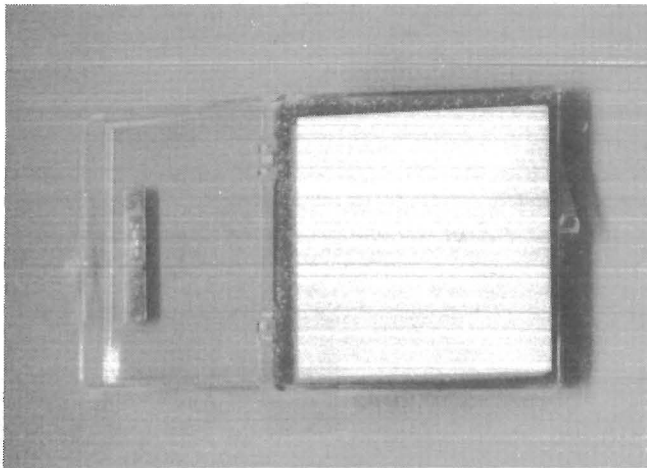


FIGURE A-6.—The reflectance standard, RS-1, a 2- by 2-in (50- by 50-mm) BaSO₄ plaque with a nominal diffuse reflectance of 98 pct.

The nominal reflectance of the board was determined by the following:

$$L = RE,$$

where L = luminance,

E = illuminance,

and R = reflectance.

Since L and R are proportional, the following equation can be derived

$$\frac{L_s}{R_s} = \frac{L}{R}$$

where L_s = luminance of RS-1 (known - measured),

R_s = reflectance of RS-1 (known),

L = luminance of the board (known - measured),

and R = reflectance of the board (unknown).

Thus, the nominal reflectance of each board was obtained by solving for R . The reflectance of the board from each photograph was calculated in the same way, except that the gray scale in the photograph served as the reflectance standard instead of the RS-1 plaque. In addition, photographs (generally 5- by 7-in size) were glued so they were completely flat against the metal plate of the positioner during the luminance measurements.

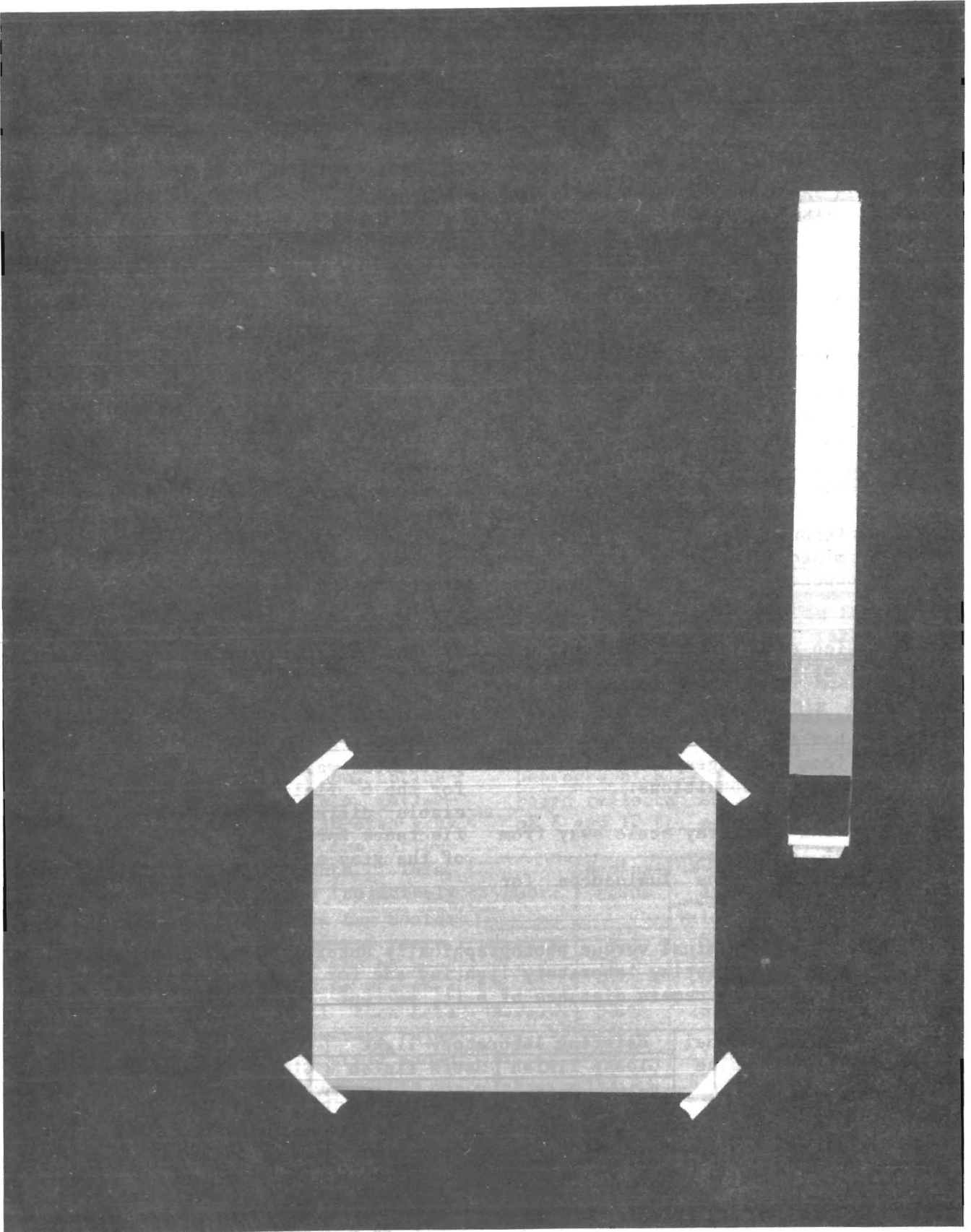


FIGURE A-7.—Board with 10-step gray scale and Kodak neutral test card (nominal 18-pct reflectance).

DISCUSSION AND RESULTS

Comparison of Flash Photographs
With Photographs Taken Under
Existing Laboratory Lighting

The results of experiment 1 are shown in table A-1. The matte-finish photographs that were taken under existing laboratory light showed the greater number of reflectance values closest to the nominal values of the boards. Photographs taken with the flash in complete darkness showed a variation of less than ± 7 pct from the nominal value of reflectance for six of seven boards. As the data show, board 6 varied considerably for both the glossy- and matte-finish flash photographs. Overall, the data show that the photographic method for determining reflectances of matte surfaces is capable of producing satisfactory results. Also, the data show only a slight difference in values of reflectance determined from matte-finish photographs as opposed to those with a glossy finish.

Evaluation of Different Positions
of the Gray Scale

This experiment was performed to investigate how the values of reflectance determined from photographs varied with several changes in conditions:

1. By moving the gray scale away from the center of the scene.
2. By measuring the luminances for determining reflectance--

a. Using the largest possible aperture position in the center of the scene.

b. Using the same size aperture as that used for the appropriate gray-scale segment and taking the measurement adjacent to the segment.

3. By changing the camera-to-subject distance to 8 and 10 ft while maintaining the same general reflectance of the scene for flash output.

Another overall aim of the experiment was to see if values of reflectances from the photographs could be obtained that were closer to the nominal board values, particularly for board 6 with a reflectance of 71.8 pct.

Table A-2 shows the results of experiment 2, for the camera-to-subject distance of 8 ft. The data for the 10-ft distance were not included because the scene was inadvertently changed when the camera was moved from the 8-ft to the 10-ft position. This change in the scene thus affected the resulting board reflectances obtained from the photograph. Accordingly, the data show slight, if any, improvement in variations of photographically determined reflectances of the boards with their nominal values. The variations in values are less for cases where the 6" field setting of the photometer was used. Further, the data for the 6" field setting showed no appreciable difference in variations of reflectance for the two different positions of the gray scale.

TABLE A-1. - Nominal versus photographically determined reflectances of boards for existing laboratory lighting and for flash in total darkness at a camera distance of 6 ft, percent

Board	Nominal value	Existing laboratory light				Flash in total darkness			
		Glossy finish		Matte finish		Glossy finish		Matte finish	
		Value	Diff. ¹	Value	Diff. ¹	Value	Diff. ¹	Value	Diff. ¹
1.....	6.4	5.7	+7	5.9	+5	9.6	-3.2	9.4	-3.0
2.....	10.4	10.7	-.3	10.6	-.2	14.3	-3.9	13.9	-3.5
3.....	23.7	24.0	-.3	23.5	+2	20.1	+3.6	20.7	+3.0
4.....	29.8	31.4	-1.6	31.5	-1.7	31.0	-1.2	31.2	-1.4
5.....	43.1	37.0	+6.1	46.8	-3.7	49.4	-6.3	50.0	-6.9
6.....	71.8	68.9	+2.9	67.2	+4.6	50.6	+21.2	50.7	+21.1
7.....	85.7	88.1	-2.4	89.3	-3.6	83.0	+2.7	84.2	+1.5

¹Difference from nominal value.

TABLE A-2. -- Comparisons of nominal and photographically determined values of reflectance for different positions of the gray scale at a camera distance of 8 ft, percent

Board	Nominal value	Gray scale 3-5/16 in from center				Gray scale 13-7/8 in from center			
		1° aperture		6" aperture		1° aperture		6" aperture	
		Value	Diff. ¹	Value	Diff. ¹	Value	Diff. ¹	Value	Diff. ¹
1.....	6.4	8.7	-2.3	8.6	-2.2	7.9	-1.5	-1.8	-1.8
2.....	10.4	13.7	-3.3	15.0	-4.6	(²)	(²)	(²)	(²)
3.....	23.7	18.0	+5.7	19.5	+4.2	14.6	+9.1	18.1	+5.6
4.....	29.8	30.8	-1.0	30.6	-.8	18.0	+11.8	29.8	0
5.....	43.1	³ 44.7	³ -1.6	45.2	-2.1	37.1	+6.0	43.6	-.5
6.....	71.8	44.4	+27.4	47.2	24.6	37.5	+34.3	44.2	+27.6
7.....	85.7	76.2	+9.5	79.4	+6.3	68.8	+16.9	76.8	+8.9

¹Difference from nominal value.

²Readings were not included because the photograph showed numerous scratches on the board.

³The 20" field was used to avoid including in the measurement a piece of tape inadvertently left on the board prior to photographing it.

Camera Distances of 8 and 10 ft
Evaluated

Nominal and Photographally Determined
Reflectances Compared for 8-ft
Camera Distance

The objectives of this experiment were to determine what the variation in reflectance from the nominal would be at the 10-ft camera-to-subject distance, and if smaller variations could be achieved overall, especially for those boards having photographically determined reflectance showing great variation in prior tests. In this test, 10 new boards were selected because the used ones had become marked up enough to show noticeable discrepancies in surface reflectance. In addition, a new 10-step gray scale was made to "tighten" the reflectance interval between segments. This, hopefully, would reduce the relatively large variation in reflectance for boards with reflectances in the 80-pct range. The results of the experiment can be seen in table A-3. Data for the 8-ft distance show a lower variation overall than data for the 10-ft distance. However, relatively large variations are still shown for boards with nominal reflectances of 38.0, 56.8, and 75.5 pct. In general, the data of this test show a significant improvement in variation from the nominal for reflectances obtained from photographs.

The basic aim of this test was to try to find out whether the highest variations in reflectance could be further reduced. Photographs were taken with a camera positioned on the tripod 8 ft away while maintaining the same scene reflectance. The results of this experiment

TABLE A-3. -- Comparisons of nominal and photographically determined¹ values of board reflectances at camera distances of 8 and 10 ft, percent

Board	Nominal value	8-ft camera distance		10-ft camera distance	
		Value	Diff. ²	Value	Diff. ²
1.....	4.1	5.6	-1.5	6.0	-1.9
2.....	15.2	14.7	+.5	14.0	+1.2
3.....	21.2	18.2	+3.0	17.0	+4.2
4.....	38.0	28.6	+9.4	28.9	+9.1
5.....	45.4	43.1	+2.3	41.7	+3.7
6.....	56.8	47.6	+9.2	38.9	+17.9
7.....	69.6	65.7	+3.9	61.8	+7.8
8.....	75.5	64.4	+11.1	63.0	+12.5
9.....	83.0	78.7	+4.3	75.1	+7.9
10.....	82.2	83.0	-.8	80.9	+1.3

¹6" field.

²Difference from nominal value.

are shown in table A-4. The data show a general improvement overall and significant improvement of 3.8 and 8.0 pct in the variations for boards 6 and 8, respectively. The variation for board 4 improved only slightly.

Film Evaluation

This experiment was performed to--

1. Evaluate different films for suitability,
2. See if a larger field on the photometer could be used to cover a larger area of the photograph and thus achieve better average reflectance for the surface of interest.

The experiment was carried out in the following way. Five boards (Nos. 1, 3, 5, 7, and 9) were selected. The scene reflectance was changed to eliminate any extraneous background and include, in addition to the board and gray scale, a neutral test card (nominal 18-pct reflectance) which would serve as an aid in processing the prints. The camera-to-subject distance was set at 7 ft. Four films were tested: Agfapan 100, Ilford XPI, Kodak Panatomic-X, and Kodak Technical Pan. Table A-5 shows the variations in reflectance from nominal

TABLE A-4. - Comparisons of differences from nominal and photographically determined values of reflectance of boards at 8-ft camera distance using this test's data and data from table A-3, percent

Board	Nominal value	This test's data, 6' field		Difference from nominal (from table A-3)
		Value	Diff. from nominal	
1.....	4.1	5.9	-1.8	-1.5
2.....	15.2	14.8	+.4	+.5
3.....	21.3	18.2	+3.1	+3.0
4.....	38.0	29.2	+8.8	+9.4
5.....	45.4	45.4	0	+2.3
6.....	56.8	51.4	+5.4	+9.2
7.....	69.6	63.9	+5.7	+3.9
8.....	75.5	72.4	+3.1	+11.1
9.....	83.0	82.1	+.9	+4.3
10.....	82.2	84.2	-2.0	-.8

values for the five boards. Generally speaking, each of the films provided satisfactory results. In addition, the data show that a relatively small variation in reflectance could be obtained by using an aperture field larger than 6' on the photometer, thus allowing the reflectance determined to be for a larger area of the photograph.

TABLE A-5. - Comparisons of nominal and photographically determined reflectances for different films at a camera distance of 7 ft,¹ percent

Board	Nominal value	Agfapan 100 (ASA 100)		Ilford XPI (ASA 400)		Kodak Panatomic-X (ASA 32)		Kodak Technical Pan (ASA 100)	
		Value	Diff. ²	Value	Diff. ²	Value	Diff. ²	Value	Diff. ²
1.....	4.1	6.2	-2.1	5.8	-1.7	6.1	-2.0	5.6	-1.5
3.....	21.2	18.3	+2.9	17.5	+3.7	18.2	+3.0	23.4	-2.2
5.....	45.4	44.7	+.7	41.1	+4.3	45.8	-.4	(³)	(³)
7.....	69.6	62.1	+7.5	61.0	+8.6	66.3	+3.3	68.4	+1.2
9.....	83.0	83.4	-.4	81.1	+1.9	84.0	-1.0	83.1	-.1

¹Pritchard setting, 1° field.

²Difference from nominal.

³Readings not included because the photograph showed numerous scratches on the board.